

Soil formation in temperate climates

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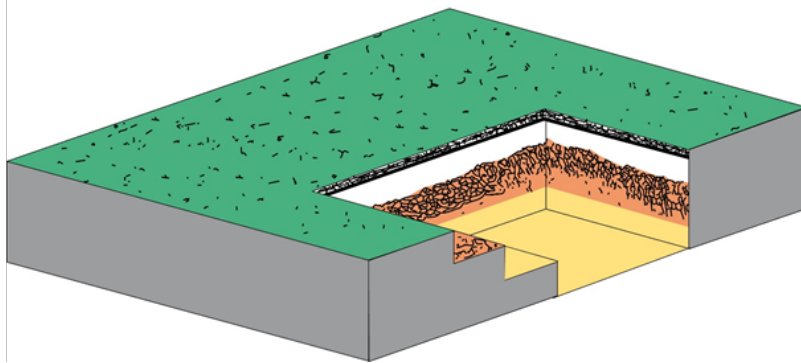
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05-01-2025



How could rocks be transformed into loose materials that can support rich vegetation? What are the specificities of soils compared to rocks and unaltered formations studied by geology? This article will insist on their organization in aggregates and the presence of a multiform porosity favourable to an intense biological activity as well as to the circulation and storage of water. The formation of soils is the consequence of alterations of various geological materials (the "parent materials" formerly called "mother rocks"), under the action of precipitations and living beings, over a long period of time. A second article will detail the factors that determine their formation, their appearance, their properties and their functioning.

1. What is pedogenesis?



*Figure 1. A soil pit excavated in a grassland. On this occasion, we can see that there are superimposed layers of different appearance and properties that pedologists call **horizons**. [Source: © Denis Baize]*

Pedogenesis corresponds to the formation and **evolution of a soil** over time, from a parent material (rock, surficial deposit) or, sometimes, from several superimposed parent materials.

As for pedogenetic processes, they are all the phenomena, natural or linked to human actions, of alterations, neogenesis, transfers, reworking, contributing to the formation and evolution of soils (see below).

To study pedogenesis, to correctly observe the different layers of the soil (called **horizons**) and to be able to take samples for analyses, it is necessary to dig pits (Figure 1). The use of an auger does not allow for satisfactory observations or adequate sampling. The descriptions on pits must be completed by the interpretation of a whole series of well-chosen analyses, entrusted to competent laboratories.

Today, when we observe a soil in a soil pit, we see the result of the sum of daily, monthly and annual functioning over 1,000, 10,000, 100,000 or 1,000,000 years. Over such long periods of time, there may have been climate changes and/or phases of erosion or new deposits. Soils therefore often have a complex appearance.

The soil that we observe, describe and analyse today is the result of the action of one, but most often several, successive and/or simultaneous pedogenetic processes having acted on an initial material. The morphology and constituents of the soil observed today integrate both **the legacy** of the parent material and the effects of these different soil forming processes.

Everything that can be **observed** today (macro- and micromorphological aspects) and **analysed** (granulometric, chemical and mineralogical analyses) is relative to **what has remained in place** and is the result of more or less important transformations. These last ones are function of:

the properties of the initial parent material;

the time elapsed since the deposit or the exposure of this material;

the aggressiveness of the successive climates.

But other properties allow us to characterize the **present functioning** of the soil:

the pedoclimate, the spontaneous vegetation, the humus form;

the composition of the water flowing down out of the soil and the present water regime;

current physico-chemical characteristics (pH, state of the Exchange Complex, etc.).

2. How does a soil differ from a rock?

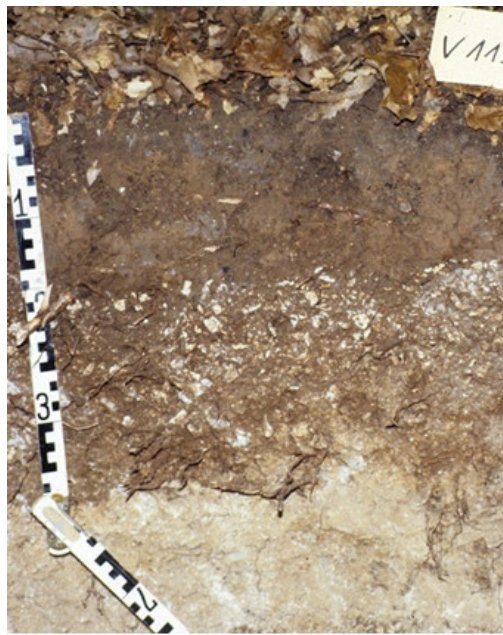


Figure 2. Soil in the process of carbonate removal. Forest soil developed in a calcareous slope deposit. In the surface horizon the pebbles have practically disappeared due to their dissolution. [Source: © Denis Baize]

To go from a rock (in the broad sense, including surficial deposits) to a soil, three series of transformations take place:

Chemical transformations of certain minerals: **alterations**

Example 1: the relatively rapid disappearance of black micas from granites, and their transformation into clay minerals;

Example 2: the progressive dissolution of calcite in calcareous soils and sediments (Figure 2).

The emergence of new mineral species: **neogenesis** or **neoformations**.

Example 1 : the formation of phyllosilicates (clay minerals),

Example 2 : the formation, from silicate minerals, of free iron oxides, not initially present in the rock,

The installation and action of **living organisms** thanks to the relative abundance of oxygen: bacteria, fungi, micro-arthropods, nematodes, earthworms, roots of higher plants, etc.

The result is a **specific organization**, a macroscopic **pedological structure** which, in most cases, results in the formation of **aggregates**. In addition, a large number of **voids** of various shapes and sizes are formed.

3. Structure and porosity

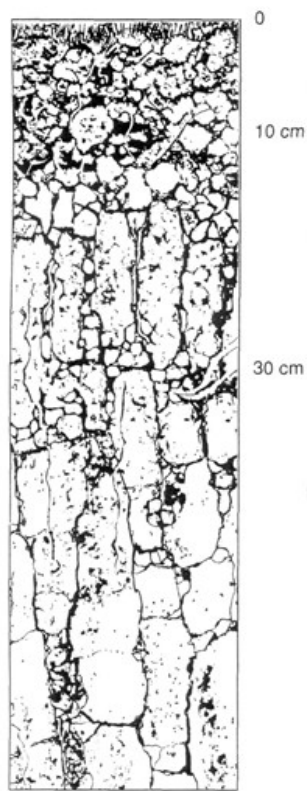


Figure 3. Appearance of soil in a pit. One can observe both different types of aggregates (prismatic at depth, large irregular polyhedra in the upper horizons) as well as inter- and intra-aggregate porosity. [Source: © David L. Rowell]

The "visible to the naked eye" **structure** of a horizon is the way in which the elementary particles **naturally** and **durably** are organized by forming small volumes called **aggregates**. The smallest are about 2 mm, the largest up to 25 cm (Figure 3).

In ploughed surface horizons, regularly reworked by agricultural tools (some break up, others compact), we also speak of structure, but then it is more a question of artificial **clods**.

Some voids have formed **within** the aggregates (root holes, interstices between particles, worm channels) and others **separate** the aggregates (stacking voids, drying cracks).

These voids allow aeration (and therefore the respiration of living organisms) as well as the storage and circulation of water, depending on their shape, size and continuity (or not).

Let's imagine a heavy rain:

All or part of the rainwater can **run off** the surface, even on a very slight slope, if the soil surface is "sealed" by tar, concrete or a slacking crust;

A part will **circulate vertically** under the effect of gravity in the largest voids ($> 10 \mu\text{m}$), provided that these voids are connected;

A part will remain in the fine porosity (between 10 and $0.2 \mu\text{m}$) but will be able to be extracted and used by the roots of the plants (it is the **available reserve**);

Another part is retained in a very fine porosity ($< 0.2 \mu\text{m}$) by capillary forces so important that water cannot be extracted by the roots;

Finally, in some cases, water can be blocked at depth by an impermeable layer (e.g. a wet clay layer). The result is a **waterlogging** of the entire porosity with a short term loss of oxygen and the installation of a reducing environment unfavourable to any aerobic biological activity (microorganisms, roots, earthworms).

4. Biology and pedology: two different worlds, different concepts

Organismes vivants BIOLOGIE	Couvertures pédologiques PÉDOLOGIE
Gènes, ADN, Génotype	Aucun équivalent
Caractères	Caractères
Phénotype	Morphologie*
Individu	Aucun équivalent
Parents	Roche-mère* Matériau parental*
Espèce	Type *
Reproduction	Aucun équivalent
Hérédité, Génétique	Héritage*
Phylogénie, Évolution	Pédogenèse*, Évolution*
Phylum, Lignage	Phylum évolutif*

Figure 4. Biology and pedology, two different fields of study with distinct concepts [Source: © Denis Baize]

In its beginnings, the science we now call pedology was strongly influenced by the concepts and vocabulary of biology [1]. The first classifications of soils were inspired by the Linnaean classification and were very heavily hierarchical and based, at least implicitly, on the idea of the existence of soil-individuals, an idea that has been refuted today. Thus, one could speak of "the genetics of soils" (title of a work by Albert Demolon, published in 1949) [2].

In Figure 4, we have placed a certain number of classical concepts of biology and pedology opposite each other in two columns. Some of the major concepts of biology have *no equivalent* in pedology! The others have only approximate equivalents indicated by an asterisk *.

Soil and land

A soil is tightly localized and cannot move (unlike air, water, wild animals...). Each soil must therefore be defined by its geographical coordinates. Unlike air and water, it usually has an **owner** and, often, a farm **operator** separate from the owner. But it is also a **common good** that provides irreplaceable **ecosystem services** to human societies. Conflicts between individual private interests and collective interests are therefore to be expected...

Soil mantles

As the word "soil" is very polysemous and as soils extend over almost all the plains territories, soil scientists now commonly use the notion of **soil mantle**. Soil mantles are very large volumes of soil forming a continuum that varies in three dimensions of space and evolves with time.

5. The notion of horizon

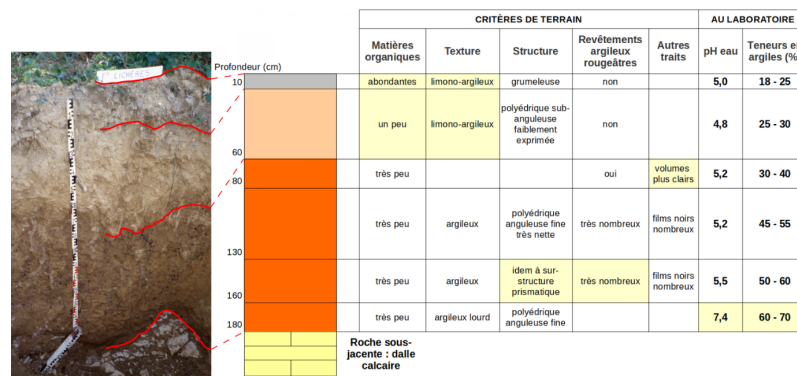


Figure 5. The distinction of horizons within a soil is based on morphological features observed in the field. The example of the soil of the Lichères forest (Yonne) is a rather complex case related to a very thick soil (1.80 m). Thanks to a few determining criteria, six horizons can be distinguished (note: in many soils, pedologists distinguish only 2 or 3 horizons). This soil shows a textural differentiation, it is not calcareous and is developed in a residual clay resulting from the total carbonate dissolution of a Jurassic limestone. [Source: © Denis Baize]

The notion of soil horizon is a key concept for pedologists, but this word does not have the same meaning as when used by geologists, for whom a horizon is a thin level that can be distinguished within a sedimentary series.

For soil scientists, horizons are the superimposed layers of a soil that have different properties from one another (Figure 5). Indeed, soils generally show differentiations along a vertical axis.

Seen in vertical section, horizons usually appear as horizontal layers of varying thickness. But sometimes their appearance, seen in a vertical trench, is much more complex (Figure 6).

A horizon can be distinguished as soon as a character considered important varies clearly. This division must be reasoned, based on morphological features observed in the field (colours, texture, structure). The limits are not always very clear.



Figure 6. Soil from ancient alluvial deposits of the river Yonne at Appoigny. The reddish clay horizons penetrate irregularly into the calcareous alluvial gravel (by carbonate dissolution). The white, vertical and equidistant marks correspond to the marks left by a mechanical toothed machine on the face of the quarry. [Source: © Denis Baize]

In all cases, the horizons are volumes, which appear macroscopically homogeneous; they are subsets of the soil mantle studied. As their thickness is measured in centimetres, they are directly perceptible to the naked eye in a pit. The horizon is the most convenient level of investigation for describing, defining and sampling soils.

The horizons are the subject of a typology according to their appearance, their functioning and the pedogenetic interpretation that pedologists give them. Codes are associated with this typology: horizons H, O, A, E, -g, S, BT...

6. Soil thicknesses



Figure 7. The boundary between soil and rock is not always easy to distinguish. Soil developed in a laminated Liassic clay (Pouilly-en-Auxois). The splitting in platelets of the parent material is preserved to a shallow depth. The soil, as an object structured in aggregates, is in reality not very thick (35 to 40 cm). [Source: © Denis Baize]

It is not always easy to know where the soil ends at depth and where the more or less weathered parent material begins (Figure 7).

In European climates, "young" soils can be said to have a thickness of between 10/15 cm and 2 m (Figures 8 and 9). But very old soils can reach thicknesses of 10 to 20 metres (e.g., the soils of the Rhodanian stony terraces).

In equatorial or humid intertropical climates of Africa or Brazil, we can consider that the soils, millions of years old, can reach thicknesses between 10 and 25 m.

7. Soil colours



Figure 8. Thin, very humus-rich alpine soil on hard limestone. Italian Alps. [Source: © Denis Baize]

Since ancient times, "earths" have been characterized and named by their colour, most often by the hue of their surface horizons, observable in the absence of vegetation.

But the colour of the surface horizon cannot provide a sufficient description of essential data (such as texture, structure, thickness, horizon differentiation) nor of chemical characteristics related to potential fertility, nor of functional characters such as water regime.

However, colours are important elements to take into account when describing soils. They guide the soil scientist in distinguishing the different horizons before beginning the systematic description that is carried out horizon by horizon. The

colour is not a misleading character: each modification is significant of a change in the proportions of one or several constituents, or of a change in their state of oxidation (case of iron).

The four main colouring agents in soils are:

iron, through its *oxides* (in the broad sense): red, orange, purplish, rusty or brown colorations in aerated environments, bluish or greenish in reducing environment;

organic matter which superimpose black, grey or brown colorations;

manganese, whose various oxides, more or less associated with iron, are concentrated in certain soil horizons where intense but temporary waterlogging occurs. Nodules, coatings, of black colour are then formed;

and the lime which gives a white coloration.



Figure 9. Thick soil developed in a loess (Oise). The soil here is about 1.60 m thick. Note the coarse prismatic structure at depth. The intact loess, yellow in colour, is visible on the last deeper 40 cm. [Source: © Jacques Roque]

In the absence of lime, the very light colours, especially clear when the soil is dry, are indicative of horizons with little humus and very low iron content. It can be an initial hue or the result of a discoloration by a pedological phenomenon. In all cases, it is the colour of the residual minerals that dominate, mainly that of the quartz.

However, a certain number of soils have a colour directly inherited from the material from which they are derived. Examples are the pink soils developed from the pink sandstone of the Vosges or the green soils resulting from the alteration of glaucony grains (Figure 10). For the others, on the contrary, the colour of the different horizons is due to the constituents that have been individualized, accumulated or concentrated during pedogenesis (clays, iron, lime, organic matter).

Soil hues do not usually have agronomic significance, but they can be used by soil scientists to:

directly recognize the presence, relative abundance, movement or accumulation of the four coloured constituents listed above;

to note the oxidized or reduced state of the iron which reflects the dynamics of the water through the **hydromorphic features** related to temporary or permanent waterlogging;

or detect some particular inherited minerals (glauccony, pink orthosis, etc.).

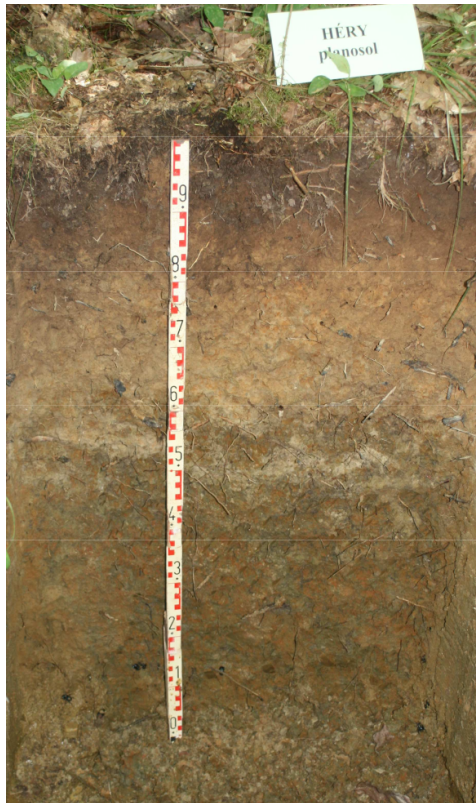


Figure 10. Green glauconitic planosol. A very acidic soil, sandy in its surface horizons, developed from a green sandy clay, itself resulting from the alteration of glauconitic Albian "green sands". Héry (Yonne). Note the white volumes visible in the upper part of the green sandy-clay horizons. These volumes have lost all their clay particles by a soil forming process called "morphological degradation". [Source: © Denis Baize]

They can therefore also help us to recognize and interpret:

the nature of the parent material;

the existence of different pedogenetic processes at the origin of the studied soil, whether these processes are ancient (linked to climates often warmer, responsible for rubefactions (red colour) by release of large quantities of iron oxides) or current;

certain fertility factors such as the presence and incorporation of organic matter, or on the contrary the risk of toxicity towards certain plants, such as the abundance of fine calcium carbonate, also called "active lime".

8. Messages to remember

Soils are formed from rocks but differ from them by a series of characteristics, in particular by the existence of an important porosity whose forms, dimensions and origins are diverse.

It is this porosity which allows the circulation of air (and water) and makes possible the life and the activity of a whole microfauna as well as the development of the roots of the higher plants. This porosity, of all dimensions, plays an essential role in the storage, filtration and circulation of rainwater.

In metropolitan France, the thickness of soils is usually between 10 cm and 2 m. But some very old soils can reach 20 m.

Notes and references

[1] Jean Boulaïne. (1989) History of soil scientists and soil science. Editions Quae. 285p.

[2] Albert Demolon (1949) La génétique des sols. **Éd.** Presses Universitaires de France - PUF.

L'Encyclopédie de l'environnement est publiée par l'Université Grenoble Alpes - www.univ-grenoble-alpes.fr

Pour citer cet article: **Auteur** : BAIZE Denis (2025), Soil formation in temperate climates, Encyclopédie de l'Environnement, [en ligne ISSN 2555-0950] url : <http://www.encyclopedia-environnement.org/?p=19706>

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